Selective NOx Recirculation Project

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$749,913 Total Contract Value ($599,287 DOE)

Overview

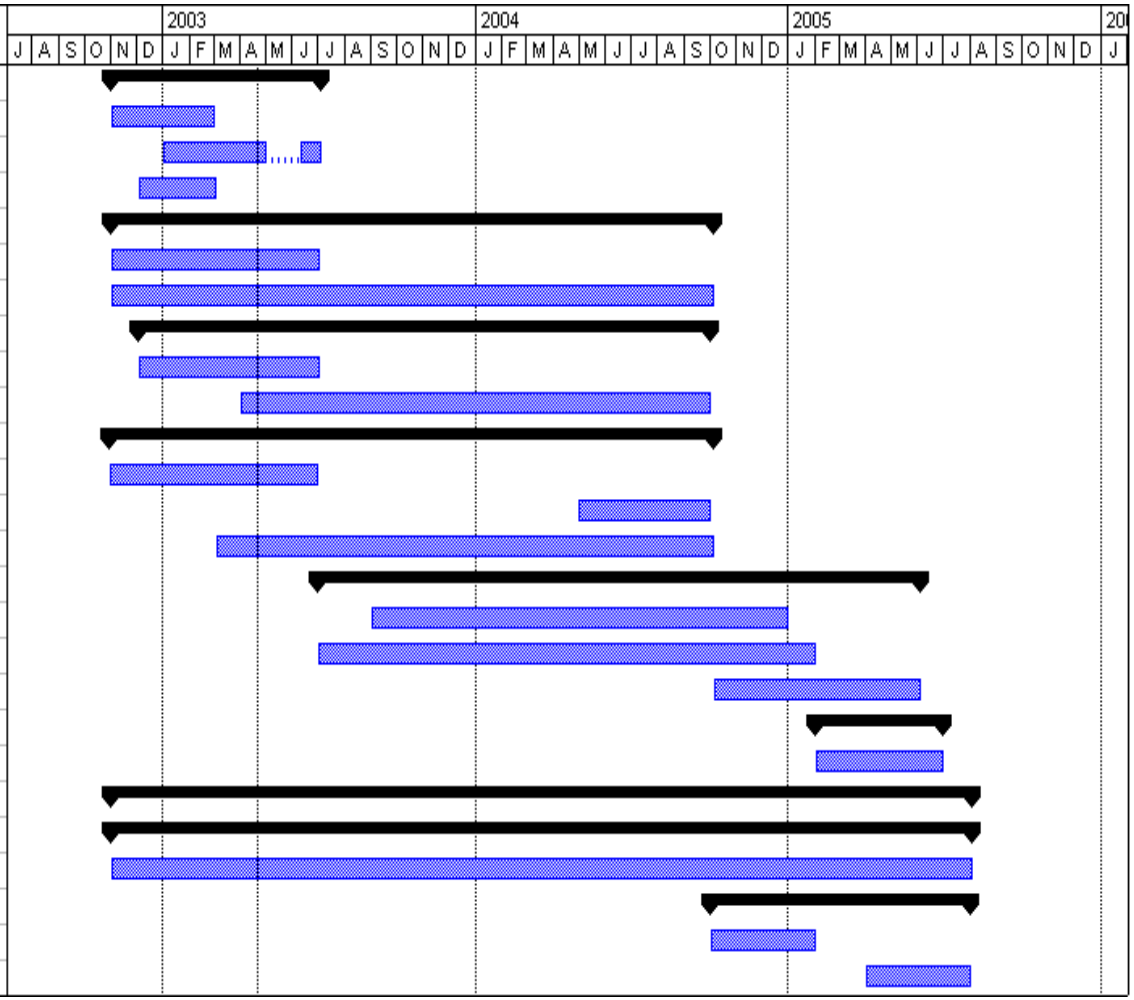
- Current NOx control technologies
- Introduction to Selective NOx Recirculation (SNR) technology
- Description and principles of SNR technology
- Proposed method of implementation
- Summary and project status

Project Goals

- Research and quantify, the mechanism and performance of the components needed for the NOx adsorption, desorption, and decomposition
- Examine the behavior of the system components through both experimental research and modeling
- Carry the research to a level where only a commercial design effort would be needed before it enters the marketplace
- Quantify the performance of this system on a 10 liter lean burn natural gas reciprocating engine and project the design for use on a large bore engine
- Enable future use of environmentally acceptable reciprocating natural gas engines to reduce NOx to 0.1 g/bhp-hr

Project Timeline

ID	Task Name
1	**Task 1.0 - Preparation of Milestone Plan (WVU)**
2	Understanding the objectives
3	Prepare bar chart schedule
4	Install engine and characterize exhaust
5	**Task 2.0 - NOx Adsorbtion**
6	Do literature search of NOx adsorbstion of the medium
7	Characterization of NOx adsorbent media
8	**Task 3.0 - NOx Desorbtion**
9	Do literature search, NOx desorbstion medium
10	Characterize NOx desorbtion on absorbent media
11	**Task 4.0 - NOx Destruction**
12	Do literature search, NOx destruction phenomena
13	Write experimental plan for NOx destruction
14	Run destruction of NOx tests
15	**Task 5.0 - NOx Loading (Measurement)**
16	Model NOx loading electronically
17	Design control, sensing and montoring system
18	Run NOx loading tests and evaluate the reduction
19	**Task 6.0 - Optimization of system configaration (Modeling)**
20	Validation computer model to optimize the system configaration
21	**Task 7.0 - Project Management, Reporting & Education**
22	**Project Management**
23	Execute project management activities
24	**Reporting**
25	Prepare presentations and status reports
26	Deliver final presentation and report



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Current NOx Reduction Technologies

- SCR (Selective Catalytic Reduction)
  - Selective catalytic reduction of NOx using nitrogen compounds such as ammonia and urea
  - NOx conversion of 70% with durability at low to mid range temperatures
  - Needs sophisticated controls and infrastructure for urea distribution

- Lean NOx Catalyst (de-NOx catalyst)
  - Catalysts that selectively promote reduction of NOx by using hydrocarbons

$$C_m H_n + (2a + \tfrac{1}{2} b) O_2 \xrightarrow{Catalyst} (a + \tfrac{1}{4} b) N_2 + a CO_2 + (\tfrac{1}{2}) b H_2 O$$

  - Passive deNOx : Uses native hydrocarbons present in the exhaust
  - Active deNOx : Requires additional hydrocarbons to be introduced

Current NOx Reduction Technologies (cont.)

- Exhaust Gas Recirculation (EGR)
  - EGR is a method in which a portion of the exhaust is recirculated by mixing it with intake air
  - Dilution of the intake air and large heat absorbing capacity of CO_2 and H_2O vapor (present in the recirculated exhaust) are believed to reduce NOx production
  - EGR requires engine retrofit, and may impact engine or lubricant life

Limitations of Current NOx Reduction Technologies for Lean Burn Engines

- Net oxidizing exhaust gas
- Lean burn continuously (no scope for catalyst regeneration)
  - Relatively low levels of CO and HC in exhaust
- Fuel penalty and in-cylinder temperature concerns when run more rich
- Small temperature range of catalyst operation

Selective NOx Recirculation Technology (SNR)

- SNR involves NOx removal from lean exhaust gas by NOx adsorption and subsequent selective external re-circulation and decomposition of NOx in the combustion process

Literature Review

- DOE researchers found that they could “destroy” NOx desorbed from sorbents, used in at a pulverized coal power plant, by recycling it to a natural gas burner or the coal burner itself (Yeh,J.J., et al., 1987)

- In 1998 researchers from Mercedes-Benz, achieved 50% NOx reduction in the lean-burn case when a barium-based NOx adsorbent material was used. They termed the process “Selective NOx Recirculation” (Chaize, E., et al., 1998)

Basic Steps of SNR

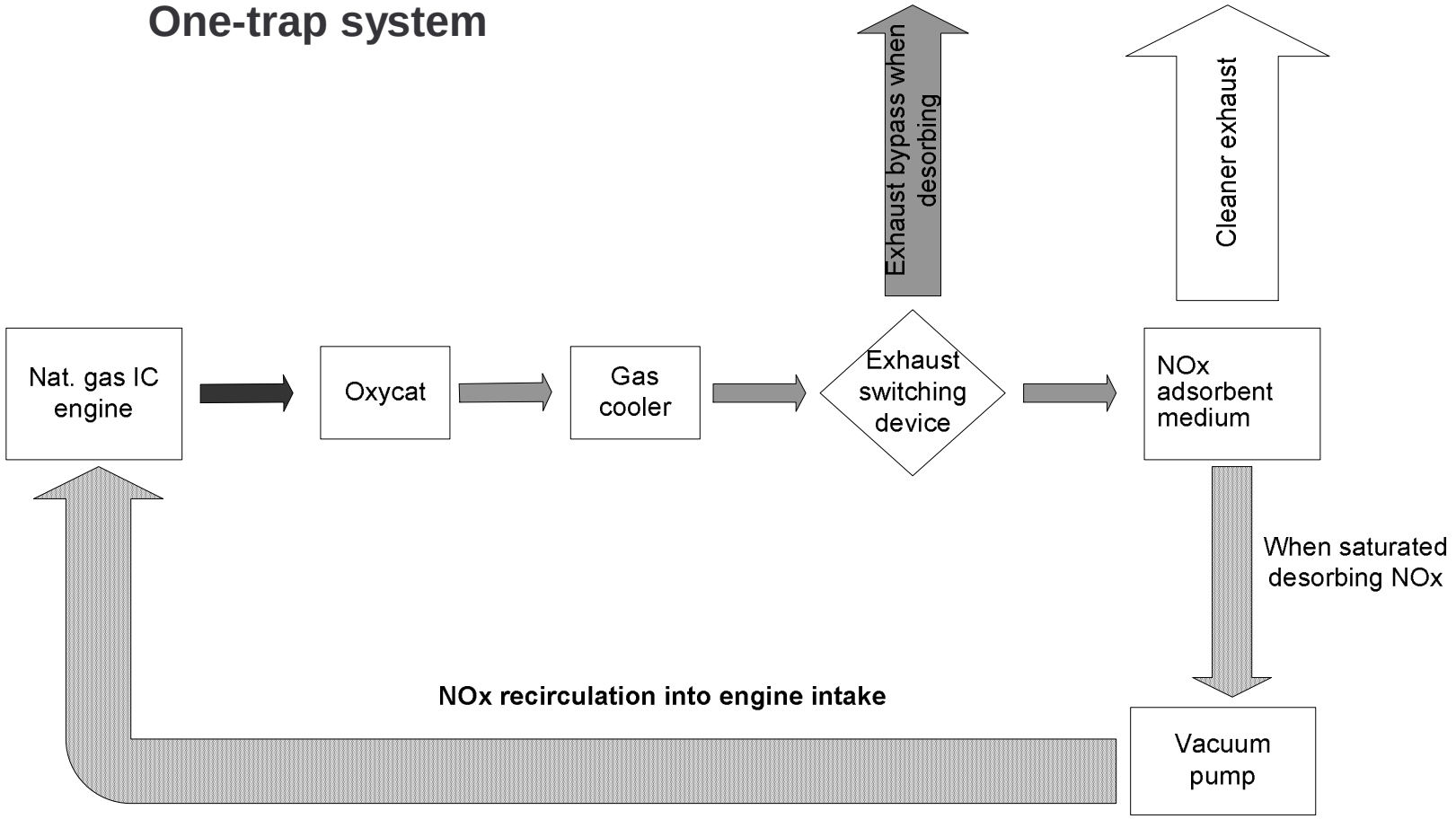
- **Adsorption:** The exhaust gas is cooled and NOx is physically adsorbed onto a carbon based adsorbent material in the passive NOx trap
  - Factors influencing NOx adsorption
    - Engine operating conditions
    - Amount of NOx being emitted
    - NOx storage media capacity

- **Desorption:** After an extended period, when the NOx quantification or breakthrough indicates trap saturation, it is quickly desorbed into a concentrated NOx system
  - Factors influencing desorption
    - Capacity of the NOx adsorption media
    - Method of desorption

Basic Steps Of SNR (Cont.)

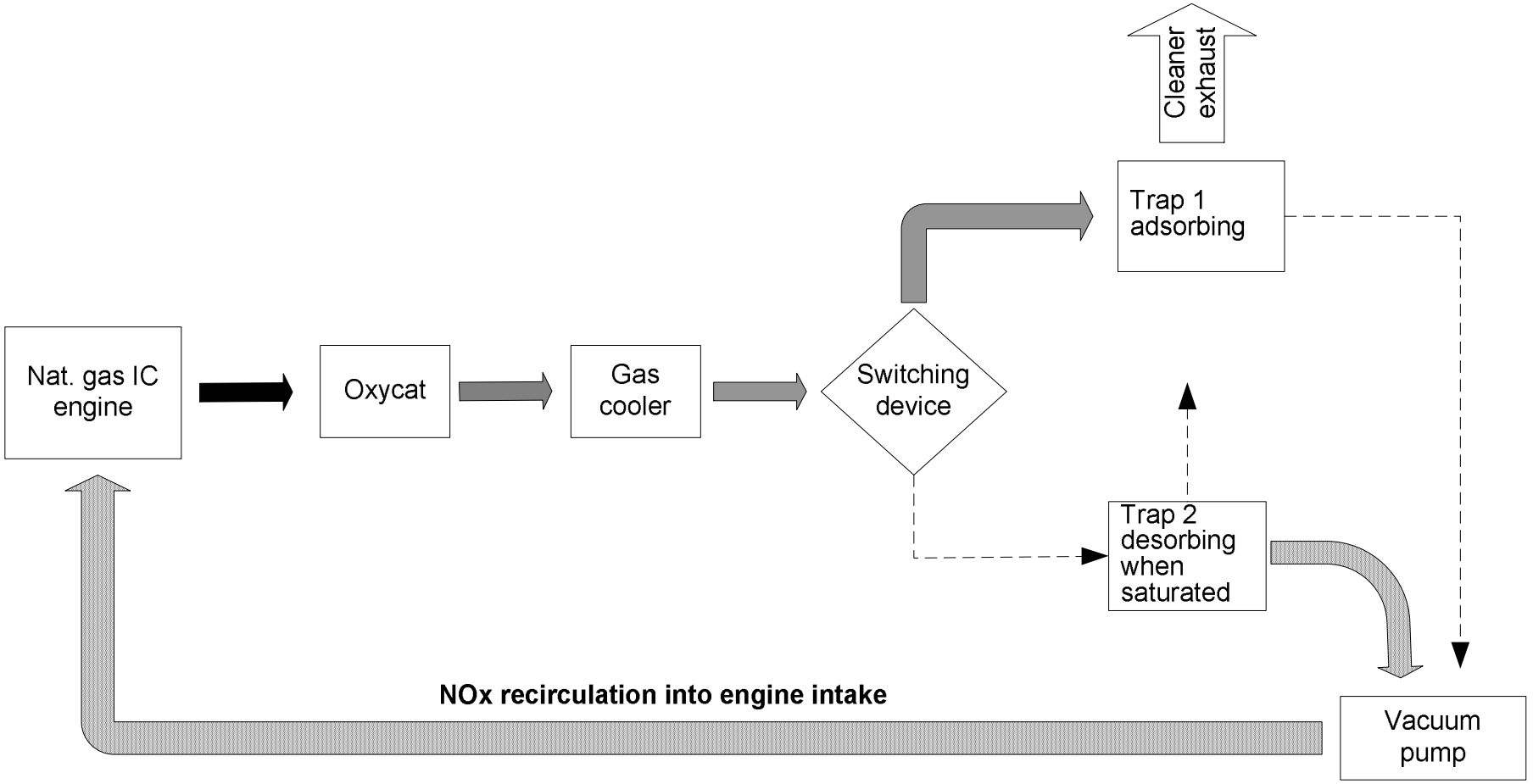
- **Decomposition:** The desorbed NOx is sent back to the air intake of the engine, where much of it is decomposed; converted to N_2 and O_2 or H_2O in the engine
  - It is presumed that the thermal NO production is decreased and the NO reduction via non-thermal NO reactions is increased (Chaize, E., et al., 1998)
  - Factors effecting NOx destruction
    - Load on the engine
    - Air-fuel ratio
    - Engine speed

One-trap system



Note: exhaust bypasses the system while desorbing

Two-trap system



Modeling of One-trap and Two-trap Systems

- One-trap system
  - The adsorber must be off-line during the desorption (regeneration) phase
  - Per-cycle average NOx adsorption efficiency is predicted to be 90%
  - It is assumed that 95% of the adsorbed NOx, when desorbed will be decomposed by the engine
  - It is assumed that desorption will take up 5% of the duty cycle and allow 5% of the exhaust to bypass, leading to a theoretical NOx reduction of 81%

- Two-trap system
  - A higher NOx reduction of 86% can be expected if the two trap system is used, because no bypass period then exists

Technical Approach

- The engine will be instrumented for torque, speed, manifold air pressure and temperature, and exhaust temperature
- Engine-out emissions will be characterized by directing exhaust to a full-scale dilution tunnel and by quantifying the concentrations of the species
- A fast NOx analyzer (*f* NOx400) will be used to measure NOx concentration
- Adsorbent materials will be evaluated and optimized by Sorbent Technologies Corporation
- Adsorbent material will be placed in line with the engine exhaust, and its ability to capture the NOx will be examined under steady state conditions
- Engine operating conditions and control parameters will be used to alter flow through the medium and NOx concentration of the exhaust

Experimental Apparatus

- Cummins L10, lean burn natural gas engine (L-10-240G)
  - Inline 6 cylinder
  - Spark ignited
  - Turbocharged
  - Rated engine power 240hp
  - Throttled controlled (manufactured by Woodward)
- Eddy current dynamometer
  - 300 hp Mustang dynamometer
  - Controlled by DYN-LOC IV (manufactured by DyneSystems Co.)

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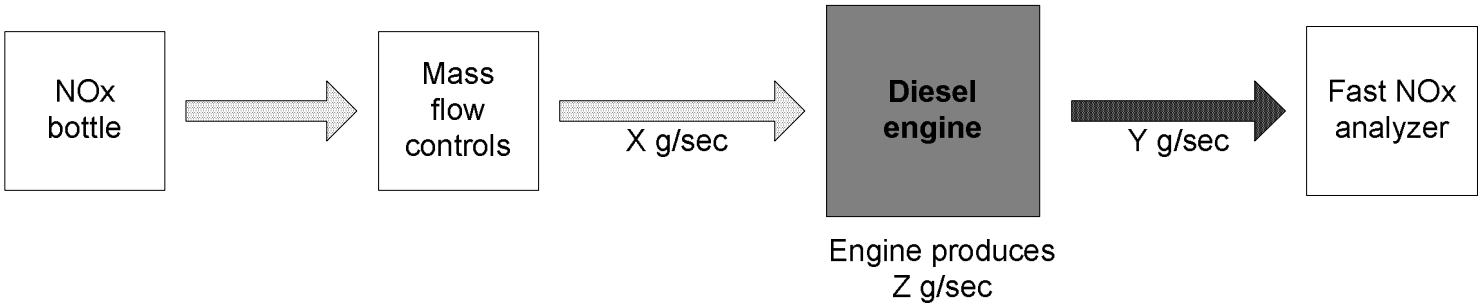
NOx Analyzer

- Fast NOx Analyzer (manufactured by Cambustion Ltd.)
  - Response time of the order of 4 milliseconds
  - Wet sampling method
  - In-cylinder sampling
  - Simultaneous two channel sampling capability

Independent Observation of NOx Destruction in Lean-Burn Engines



$$\text{NOx destruction} = \frac{X - (Y - Z)}{X}$$

Current Progress

- Understanding of NOx adsorption phenomena – In Progress
- Installation of engine and characterization of its exhaust – In Progress
- Design and setup of NOx injection system to evaluate destruction of NOx in lean-burn engines – In Progress